Effective Detection of Glaucoma from Fundus Images using Computational Intelligence Technique

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Abstract: Painless eye disease which manifests as gradual loss of vision is called as glaucoma. The accuracy of clinical techniques is less and early stage detection is not possible. The paper presents an automated detection method that uses wavelet features extracted from fundus image and classify them withartificial neural network. Proposed method detect glaucoma in very less time and accuracy is 92.8%.

Keywords: Glaucoma, fundus image, wavelet transform, image processing, artificial neural network.

Introduction

Sense organs are the sensors of the living body that senses the external stimuli and convert it to electrical impulses. These impulses are processed in brain and appropriate action is taken accordingly. Eyes are considered as the most important sense organs. Following diabetic retinopathy, the second most prominent reason for blindness throughout the world is glaucoma. The number of people blind due to glaucoma are above 3 million globally. The expected growth rate of glaucoma cases is 33.33% which will lead to 80 million cases by 2020 from 60 million at present [1].

The appropriate production, flow and drainage of aqueous humor in eye is necessary for healthy eye. But in glaucoma affected eye, this drainage gets clogged which causes obstruction to the flow of aqueous humor. The intraocular pressure within the vitreous chamber increases due to the improper drainage. As time goes on, optic nerve which comprises of bundle of nerve fibers gets damaged with this rise in pressureand results in loss of vision. The main concern of glaucoma is that unlike other disease it has no earlier symptoms. The person suffering from glaucoma does not feel any pain in eye only vision loss occurs. The reason for this loss of vision is considered aging, not glaucoma. When the patient experience the signs, major loss has already occurred. Shortage of skilled ophthalmologists for detecting glaucoma by ophthalmic methods makes the situation much worse in African countries.

Classification is mainly done in two categories:

Open Angle Glaucoma

The entrance to drain is clear,i.e. the angle formed by iris and cornea isopen as shown in Figure 1. [2]. But the flow of aqueous humor is slow which leads to development of pressure gradually over a long period of time.

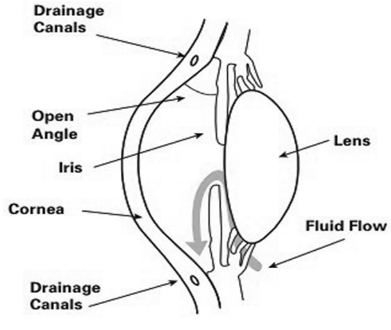

Figure 1. Open Angle Glaucoma [2]

Angle Closure Glaucoma

Lens get stuck to the iris which leads to closing of the angle between iris and cornea as shown in Figure 2. This makes it difficult for aqueous humor to drain to the drainage canal [2]. Aqueous humor starts flowing to the vitreous chamber and pressure builds up rapidly. This sudden rise in pressure leads to vision loss and medical emergency.

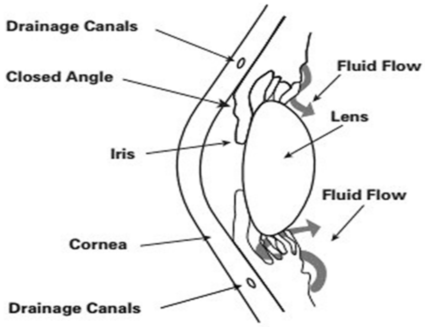

Figure 2. Angle Closure Glaucoma [2]

Clinically, glaucoma is detected by measuring the pressure of the eye using tonometer or by checking the visual field obtained through perimetery approach. But these approaches are less accurate. Student sight saver program was conducted and the accuracy using the clinical technique obtained was less than 60% [3]. The ophthalmoscopy technique requires to dilate the eye which is painful to the patient. So considering these factors there is a severe need to design an accurate and computationally efficient system to detect glaucoma. The automated approach will provide the ophthalmologist a second opinion for diagnosis.

The method proposed in this paper uses the wavelet features such as mean and energy of the wavelet coefficients obtained using different wavelets from the fundus image. The wavelets which provides frequency information along with spatial information of an image are more effective for detection in comparison to the use of only spatial features. Artificial neural network which models the biological network is considered for the classification of the fundus image as glaucoma affected fundus image and normal fundus image. The artificial neural network is computationally efficient than some of the other methods such as support vector machine. With the usage of artificial neural network, computation time decreases.

The paper comprises of mentioned sections in the following order: The approaches for automated detection process present in literature are outlined under the heading related work in section 2. The next section discusses the proposed methodology which involves preprocessing, feature extraction using wavelets, classification with artificial neural network. The performance parameters such as accuracy, specificity, sensitivity for two databases are listed in next section. Section 6delineate the various comparisons in the form of tables. The justification of results and conclusion are drawn towards the last sections.

Related Work

In literature, many image processing approaches for glaucoma detection are available. Homogeneity, energy, contrast and correlation which are collectively termed as gray level co-occurrence matrix features were extracted from ocular thermal images and used for detection [4]. The retinal nerve fiber layer thickness was used as parameter and classification was done using artificial neural networkfor detection [5]. The main focus was to segment the optic cup as well as optic disc when fundus images were used for detection. Ratios such as rim to disc along with cup to disc were measured to detect glaucoma. The authors used support vector machine to classify fundus image [6]. A novel machine learning method used intensity and frequency based features. Feature matrix was reduced using principal component analysis [7]. In another approach, the texture features which measures the neighborhood pixel relationship as well as higher order spectra features were used [8]. Superpixel classification was performed on the fundus image to detect the optic disc and cup, which were further used to classify the fundus image as glaucoma and normal [9]. The hybrid approaches were also presented in some research works. The authors [10] used the hybrid of structure feature such as cup to disc ratio along with intensity features for detection. The results from individual classification were combined and used for final detection. Various classifiers were used to classify the fundus image into glaucoma and normal fundus image, on the basis of third and fourth order moment features [11]. The hybrid approach was extended to the combination of spectral features and spatial features such as mean and energy along with the structural features for detection [12]. Wavelet features were extracted from segmented optic disc to detect glaucoma. The feature selection algorithms such as genetic algorithm were also used to reduce the computation burden [13].

Statement

The paper describes an automated technique for detection of glaucoma which is effective in terms of accuracy. Fundus images are processed using digital image processing techniques. For classification of the fundus image, computational intelligence technique artificial neural network is utilized.

Innovative Content

Automated process for glaucoma detection is the need as the accuracy is low and complexity is high in the clinical detection process. By 2020, about 5.9 million people will be blind from both the eyes due to open angle glaucoma [1]. The clinical techniques are available to detect glaucoma but are less accurate [3] and lead to the diagnosis at later stage when person has lost significant amount of vision.

The main focus till now in the automated detection process was the calculation of ratio called as cup to disc ratio from the fundus image and classify it into glaucoma fundus image on the basis of the ratio value. But these approaches are complex and are database dependent.

With research, the direction get aligned to the extraction of features. Many features were extracted such as intensity and gray level co-occurrence matrix features, spatial features. The spatial features are limited as these provide pixel intensity value not the hidden frequency content.

The spatial and frequency content both are accessible using the wavelet features which makes them an optimum choice for feature extraction. Wavelet features are considered in the approach described in the paper. Moreover the classifiers used in literature are mostly support vector machine which are not computationally efficient. The proposed method uses the artificial neural network which reduces the computational time for classification. With this method, the detection can be done with the use of graphical user interface by an untrained person. The software for implementation is MATLAB R2013a. Figure 3 depicts the flowchart for the proposed method.

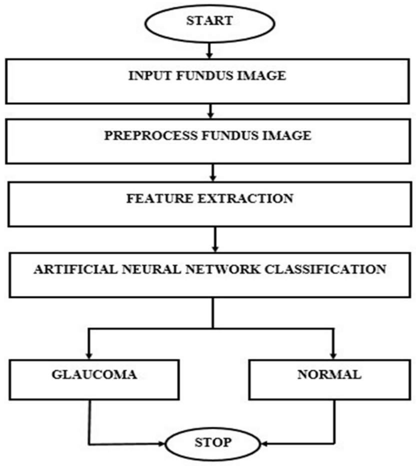

Figure 3. Flowchart for proposed method

Fundus Image Acquisition

Fundus images are captured using the fundus camera. Fundus camera is embedded with a low power microscope which help to capture retina, optic disc, and optic nerve head. Databases are downloaded from online sources. One dataset consist of 30 high resolution images [14]. Drishti-GS database consist of 101 images which are verified by four eye experts. Almost equal number of male and female patients were selected in the age group of 40-80 years 15]. Figure 4 shows the fundus camera displaying fundus image.

Figure 4 Fundus Camera displaying fundus image

Resizing the fundus image
The fundus images acquired from the database are of large dimension so resizing is done to convert the all images to standard value so that analysis can be done easily. Figure 5 depicts the user interface showing the resized image when the RESIZE INPUT IMAGE pushbutton is pressed.

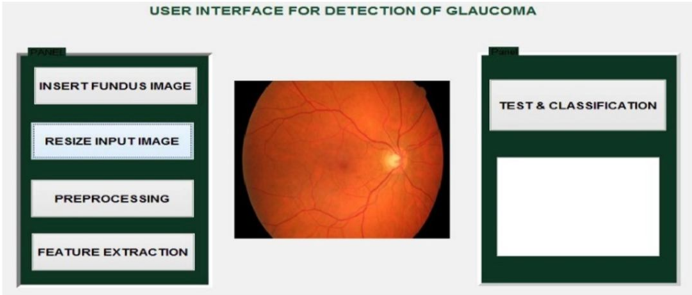

Figure 5 User interface showing the resized image

Preprocessing
The preprocessing stage is for preliminary processing of the fundus image which leads to better feature extraction. In the proposed approach, the two main processes are performed in this stage conversion of the colored image to gray level image and filtering. The gray level conversion is done to reduce the computation burden. The RGB (Red Green Blue) channel image is converted to gray scale as the memory required by colored image is large as compared to gray scale. Noise removal is done using median filteringas it preserves the edges. Figure 6 shows the user interface for pre-processed fundus image.

Figure 6. User interface for pre-processed fundus image

Feature Extraction
Prominent role is played by the extracted features in the image processing techniques for detection purpose. Many type of features are used in literature for the detection such as gray level co-occurrence matrix features, intensity features and structural features [6, 13-15]. These features provide the spatial domain analysis but high frequency contents are not considered which make them ineffective at some point. Wavelet features provide both spatial and frequency analysis. Small wave of finite duration and varying frequency is called as wavelet. These act as the foundation for representing image in various degree of resolutions. Discrete Wavelet Transformation (DWT) is a mean to resolve the image into multiple degrees. The decomposition of image can be done at multiple levels and each level provides individual approximation and detailed coefficient. Figure 7 depicts decomposition of image into coefficients at first and second levels.

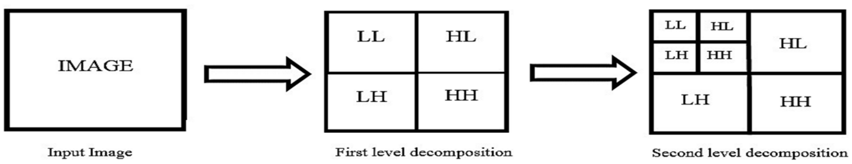

Figure 7. Wavelet decomposition

In the paper, the first level decomposition is done and that provide the following coefficients.

i. Approximation coefficient (A)

ii. Horizontal detailed coefficient (Ch)
iii. Vertical detailed coefficient (Cv)
iv. Diagonal detailed coefficient (Cd)

Higher level decomposition is not required in the detection process and also their usage increases the complexity of the system. Matrix is formed by these first level decomposition coefficients. The extracted features consist of the mean as well as energy of these coefficients obtained from the fundus image.

The mean of detailed coefficients is

$$\text{Mean Coef} = \frac{1}{p \times q}\sum_{x=\{p\},y=\{q\}} |c(x,y)|$$

Energy of detailed coefficient

$$\text{Energy Coef} = \frac{1}{p^2 \times q^2}\sum_{x=\{p\},y=\{q\}} \left(c(x,y)\right)^2$$

whereCoef is the wavelet coefficient in the form of matrix
p and q are the number of rows and columns in the wavelet coefficient Coef.
$c(x,y)$are the elements of the matrix Coef.
Mean and energy corresponding to detailed coefficients obtained using different wavelets are used such as daubechies (db3), symlet (sym3), biorthogonal (bior3.3, bior3.5, bior3.7) and haar (haar). Feature vector comprises of eighteen such features extracted.

Artificial neural network classification

Biological nervous system inspired artificial model which processes the information as the brain does is termed as artificial neural network. Neurons which are the backbone of the artificial neural network work collectively to solve a particular problem. These neurons are generally called as processing elements are extremely interconnected. The link between each layer neurons is having some weight which carries the relative importance of input [16]. The proposed method uses back propagation network which is a supervised learning algorithm. The error which is the difference between the targetoutput and obtained output is feedback to the network while training stage. In the proposed method, the architecture of the network consist of an input layer with 18 neurons, single hidden layer and an output layer. The artificial neural network classifies input fundus image into glaucoma or normal image. Figure 8 depicts the user interface classifying the fundus image.

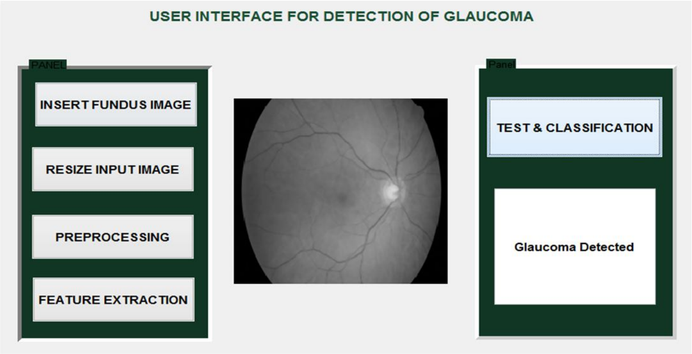

Figure 8. User interface classifying fundus image as glaucoma image

Results and Sensitivity Analysis

Three performance parameters are considered for evaluation and the appropriate formulae for each are listed as

$$\text{Sensitivity} = \frac{TP}{TP + FN}$$

$$\text{Specificity} = \frac{TN}{TN + FP}$$

$$\text{Accuracy} = \frac{TP + TN}{TP + FP + TN + FN}$$

where

TP stands for True Positive anddefines the number of glaucoma fundus images which are categorized as glaucoma fundus image.
TN stands for True Negative and defines the number of normal fundus images which are categorized as normal fundus image.
FP stands for False Positive and defines the number of normal fundus images which are not categorized as normal fundus image.
FN stands for False Negative and defines the number of glaucoma fundus images which are not categorized as glaucoma fundus image.
Database 1: The database consist of 30 images out of these, normal and glaucoma fundus images are of equal proportions. 16 fundus images and 14 fundus images are utilized for training and testing respectively. The performance parameters obtained are indexed in Table 1.

Table 1. Performance parameters for Database 1

Classifier	Sensitivity (%)	Specificity (%)	Accuracy (%)
Artificial neural network	85.7	100	92.8

Database 2: Dristi-GS database consists of 101 fundus images from which 51 fundus images and rest 50 fundus images are utilized for training and testing respectively. Table 2 list the performance parameters obtained.

Table 2. Performance parameters for Database 2

Classifier	Sensitivity (%)	Specificity (%)	Accuracy (%)
Artificial neural network	92	88	90

Comparison of Results

The most important parameter in the detection process is the accuracy of the automated system. The system is effective than others if it is more accurate. In this section two comparisons are done, one compares two type of database. Another compares different methods proposed in literature. Table 3 compare the two databases.

Table 3. Comparison of databases used in the method

Database	Accuracy (%)
Database 1	92.8
Database 2	90

Table 4delineates the difference in the performance parameters of the other techniques present in literature and proposed method for automated detection process for glaucoma.

Table 4 Comparison with existing methods in literature

Technique	Sensitivity (%)	Specificity (%)	Accuracy (%)
Retinal Nerve Fiber Layer thickness and Artificial neural network classifier [5]	60	100	81.5
Moment features and Support Vector Machine classifier [11]	NA	NA	86.57
Ocular Thermal Images using GLCM features and Logistic Regression classifier [4]	60.6	70.3	88.8
Cup-Disk and Rim-Disk Ratio and Support Vector Machine classifier[6]	100	80	90
FundusCup to Disc Ratio, hybrid Features and Support Vector Machine [10]	100	88	92
Proposed Method	85.7	100	92.8

Justification of Results

There are two main reasons for the improvement of accuracy of the proposed method. First is the use of wavelet features and another is computationally intelligence method artificial neural network. Some of the methods proposed in literature, use cup to disc ratio as feature but the improper segmentation of optic disc contributes to inaccuracy. Features such as energy, correlation and homogeneity obtained using gray level co-occurrence matrix use only the spatial domain of image ignoring the frequency content. But the work proposed in the paper uses the wavelet features which considers spatial and frequency content of the fundus image contributing to the improvement of accuracy. Artificial neural network are robust to noisy and missing data, this feature of artificial neural network also contributes to the improvement of accuracy. The usage of back propagation artificial neural network makes the network to learn faster which improves the computational time of the proposed work.

Conclusion

In this work, the automated detection process for glaucoma has been developed. The approach used is a mixture of computational intelligent techniques such as image processing and artificial neural network. A graphical user interface is designed for the detection process so that a layman person can use the automated process. The fundus image is given as input to the system and the intermediate stages can be viewed in the graphical user interface. Fundus image is classified as glaucoma affected and normal using artificial neural network. Computation time for detection is about 10 seconds. The accuracy achieved using the proposed technique is 92.8%. Automated detection system for glaucoma was implemented using MATLAB R2013a.

Acknowledgement

We are highly indebted to the Director, GNDEC, Ludhiana for furnishing us with the means necessary for the implementation of the research work.

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